Principles of Physics

Sixth Edition, with SI Units

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Note on 1977 Reprint

In this reprint, the text concerned has been adjusted to show how the specific heat capacity of a metal can be found by transfer of mechanical energy to heat, and more recent examination questions have been added to the exercises.

I am particularly indebted to Chief Olu Ibukun, UNESCO Regional Office of Science and Technology for Africa, for the new photograph showing a scientist at work at the Solar Energy Laboratory, University of Dakar, Senegal.

Preface to Sixth Edition

In this edition, I have added: (*a*) a concise 'Introduction to Astronomy' chapter 35, covering the main points required in the Ordinary level Nuffield syllabus; (*b*) another Multiple Choice question paper for further examination practice; (*c*) clarification of some points in the text and recent examination questions; (*d*) additional photographs at the beginning of chapters.

The author is indebted to many correspondents at home and abroad for their constructive comments, especially F. Anstis, Reed's School, Surrey, J. Lister, Wheelwright Grammar School for Girls, A. Loizou, The English School, Cyprus, and W. G. Sale, Nairobi, Kenya. He is particularly grateful to Dr R. A. McCurrie, University of Bradford, for his advice on domain theory in magnetism.

Preface to 1973 Edition

Principles of Physics was first published in 1951 and during the succeeding years it has been regularly brought up to date as new topics have been included in the GCE O level syllabuses. However, there has been so much change in these years that the time has now come for a complete replanning of the book in SI Units.

In this new edition, the text is based on the revised Ordinary level syllabus of the Examination Boards and the Nuffield Ordinary level examinations.

The book has been completely redesigned and reset with new diagrams and photographs.

Among the changes for this new edition, mention may be made of the following:

(1) SI units have now been used. Where they are more convenient for calculations, allowed sub-multiples of mass and length, the gramme and centimetre, have also been used;

(2) in *Dynamics*, vectors and scalars, linear momentum and circular motion have been discussed and modern apparatus introduced;

(3) in *Heat*, the joule is used as the heat unit, electrical heating has been utilized, and conversions to heat energy discussed;

(4) an introduction to the molecular view of solids, liquids and gases, and to the properties of matter, has been given in *Molecules and Matter*;

(5) in *Waves*, the differences between matter waves and electromagnetic waves have been discussed, their common properties described, and an introduction to interference and diffraction has been given;

(6) in *Electricity*, prominence has been given to electrons and ions as charge carriers in metals and electrolytes, to the link between potential difference and energy, and to the concept of magnetic fields in electromagnetism;

(7) the section on *Electronics* contains an account of hot and cold cathodes, the diode valve, the fine beam tube and its uses, and to semiconductors, junction diode and transistor amplifier;

(8) the final chapter on *Radioactivity* includes an introduction to atomic structure and nuclear energy.

Many worked examples have been given in the text in illustration of the subject matter and there are numerous exercises to assist comprehension. It is hoped that the book will provide a useful modern introduction to the principles of the subject.

I am very much indebted to the following for their assistance in compiling the work: M. V. Detheridge, William Ellis School, London and S. S. Alexander, Woodhouse Grammar School, London; L. J. Beckett, William Ellis School, London; R. P. T. Hills, St. John's College, Cambridge; and T. E. Walton, William Ellis School, London. I am also indebted for valuable advice in earlier considerations to F. C. Brown, head of the physical sciences department, Institute of Education, London University.

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The author is indebted to the examining boards listed for their kind permission to translate numerical values in past questions into SI units; the translation is the sole responsibility of the author.

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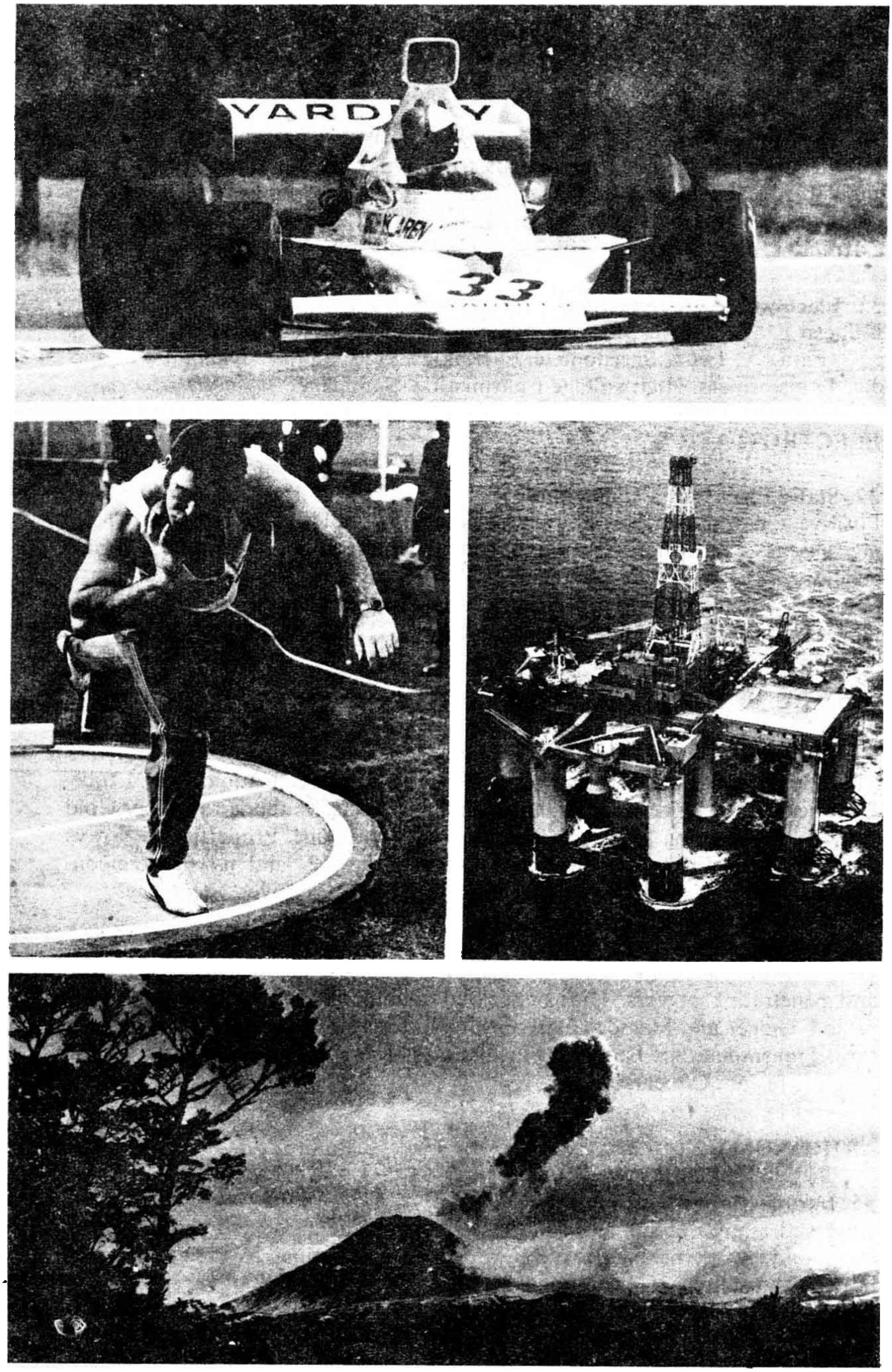

Physics in action. *Top:* A Formula 1 racing car capable of speeds up to nearly 300 km/h. *Centre left:* A world class shot-putter can propel the 7·26 kg shot more than 21 m. *Centre right:* One of the latest drilling platforms of the type used to prospect for oil beneath the sea. *Bottom:* An active volcano: Mt Ngaruahoe, New Zealand, during eruption.

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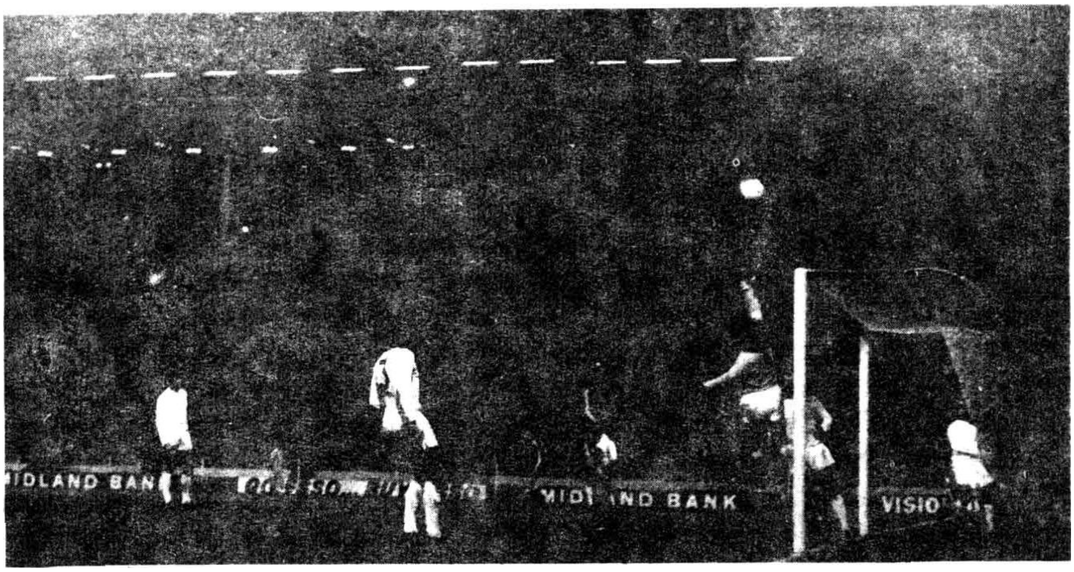

Soccer at Wembley Stadium, London. The photograph shows changes of (i) chemical energy to mechanical energy (in the form of kinetic and gravitational potential energy), (ii) electrical energy to light energy, (iii) potential to kinetic energy and vice versa.

1

Introduction

Theory and Experiment · Forms of Energy · Units · Measurements · Graphs

PHYSICS is a science concerned with the behaviour of matter. Some of its branches are electricity, optics, heat, sound, properties of matter and atomic theory.

Scientists of many different nationalities, such as British, American, Russian, French, Italian, Japanese and Chinese, are today engaged in researches in physics. As a result, many useful inventions and machines have been produced. Radar control at London and other large airports; computers in banks; colour television transmission by British and other national radio corporations; high-power microscopes for use in laboratories; and anti-skid tyres for cars, have all developed from researches in physics.

THEORY AND EXPERIMENT

In ancient times people believed something simply because a famous person said it. A good example occurred in the case of falling objects. A famous Greek philosopher called Aristotle said that heavy objects always fell to the ground faster than light objects. This was believed for nearly 2000 years.

An experiment showed that this statement was incorrect. A heavy and a light object were dropped together from the top of a tall building. (Legend says that the building was the Leaning Tower of Pisa in Italy, which still exists.) It was observed that, contrary to what Aristotle thought, the heavy and the light object *both* reached the ground at the same time. Aristotle's theory was therefore wrong.

Today, scientists will not accept a theory unless there is experimental evidence to support it. If an experiment gives results which are contrary to the theory, the theory is abandoned or modified. Sometimes the result of an experiment suggests a theory. About 1910, for example, Lord Rutherford examined the results of an experiment by two of his research students at Cambridge. They were firing tiny particles at atoms. Some of the particles bounced off at large angles on making collisions. Some even bounced back. He came to the conclusion that the atom contained a very tiny concentrated mass in the middle which repelled the particles violently. He called it the *nucleus* of the atom. And this led years later to the discovery of nuclear energy and then to the development of the large nuclear power stations throughout Britain today.

FORMS OF ENERGY

'Work' and 'Energy' are two ideas which are widely used in all branches of physics.

A boy pulling a sledge or a girl pushing a pram are said to do *work*. Any object which produces movement is said to do work. Thus on climbing the stairs, we do work in moving our bodies upward. If an object has the capacity for doing work, it is said to have *energy*. The spring of a watch when wound up has energy because it moves gear wheels as it slowly unwinds. A cricket ball thrown at the wicket has energy because it can knock down the stumps.

The wound spring and the fast-moving cricket ball are examples of objects having *mechanical energy*. Over the past centuries, scientists gradually realized that there are many different forms of energy. An electric motor uses *electrical energy* to drive an electric train. *Light energy*, falling on a light meter used in photography, causes a pointer to move across a scale. *Sound energy* causes a microphone diaphragm or thin plate to vibrate. *Chemical energy* is the source of energy in our food which makes us grow and also provides us with muscular energy to move objects. *Nuclear energy*, the energy in the nucleus of atoms, produces heat energy, which in turn is used to generate electrical power in nuclear power stations.

ENERGY CONVERSIONS · PRINCIPLE OF CONSERVATION OF ENERGY

By means of suitable machines or apparatus, energy can be changed from one form to another. This is illustrated in Fig. 1.1. Thus a steam engine converts heat energy to mechanical energy. Mechanical energy is converted to heat energy when a match is struck. A light meter or photoelectric cell converts light energy to electrical energy. An electric lamp converts electrical energy to light energy. A solar cell converts the heat of the sun to electrical energy to power space ships. An electric fire converts electrical energy to heat energy. A microphone converts sound energy to electrical energy. A tele-

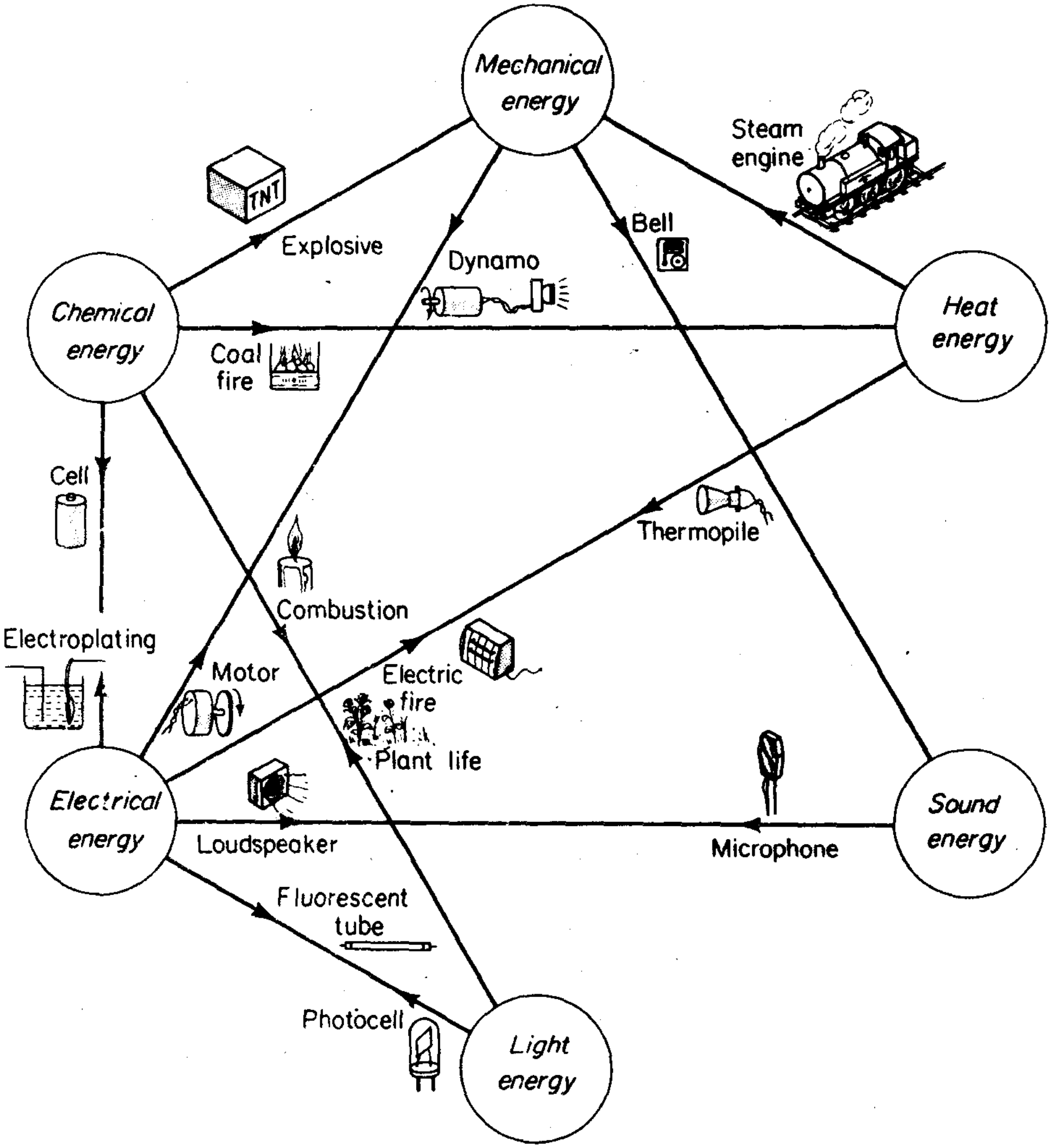

Fig. 1.1 Energy and transformations

phone earpiece converts electrical energy to sound energy. A battery converts chemical to electrical energy; a reverse change occurs in electroplating. The energy from the sun produces chemical changes which make plants and trees grow, and the energy is stored underground in coal centuries later, after the wood is absorbed by the soil and sinks.

An electric plant at a power station illustrates how energy can be changed from one form to another until a desired form of energy is produced. Coal is first burned, so that heat energy is produced from chemical energy. By means of a steam engine or turbine, the heat energy is converted into mechanical energy, which turns the coils of an electric generator. Electrical energy is then produced. Electric lamps and heaters in homes and buildings now convert electrical energy to light and heat energy. Finally, the light energy collected by the eye falls on nerves in the retina, which stimulates the sensation of vision.

The heat energy received by the steam turbine is not all converted into mechanical energy. Some of the energy is wasted in overcoming the frictional forces in the wheels of the turbine. Sound energy is also produced by the spinning wheels owing to air disturbance. However, if the whole generating plant receives 100 units of energy, initially in the form of heat from the coal used, the total energy produced, calculated by adding together all the different forms of energy, will still be 100 units.

This leads to a generalization known as the *Principle of the Conservation of Energy*. It was arrived at after many years of experience, and it is recognized today as one of the most important principles in science. It states that, *in a given or closed system, the total amount of energy is always constant, although energy may be changed from one form to another.*

Units · Measurements

SYSTÈME INTERNATIONAL (SI) UNITS

A new system of units, known as the Système International (SI) units, has been adopted for all branches of physics. It is based on the metre as the unit of length, the kilogramme as the unit of mass, the second as the unit of time, the ampere as the unit of electric current and degrees kelvin as units of temperature. The unit of force in this system is the newton and the unit of energy is the joule (pp. 44, 55).

The *metre* (*m*) was for many years the distance between two lines on a particular platinum–iridium rod at 0°C which is kept near Paris. It is now defined as the length of a certain number of wavelengths in a vacuum of a particular orange radiation of the krypton-86 atom. Unlike the distance between the marks on the rod, the wavelengths are due to atomic vibrations and remain constant. Thus

1 m = 1 650 763·73 wavelengths of the above radiation.

The *kilogramme* (kg) is the mass of a particular solid cylinder made of platinum–iridium alloy kept in Paris, known as the International Prototype Kilogram.

The *mean solar day* is the average period between successive transits of the sun across the meridian, taken over twelve months, at any part of the earth's surface.

In practice, the following smaller units may also be used:

The *millimetre* (mm), which is $\frac{1}{1000}$ part of a metre.
The *centimetre* (cm), which is $\frac{1}{100}$ part of a metre.
The *gramme* (g), which is $\frac{1}{1000}$ part of a kilogramme.